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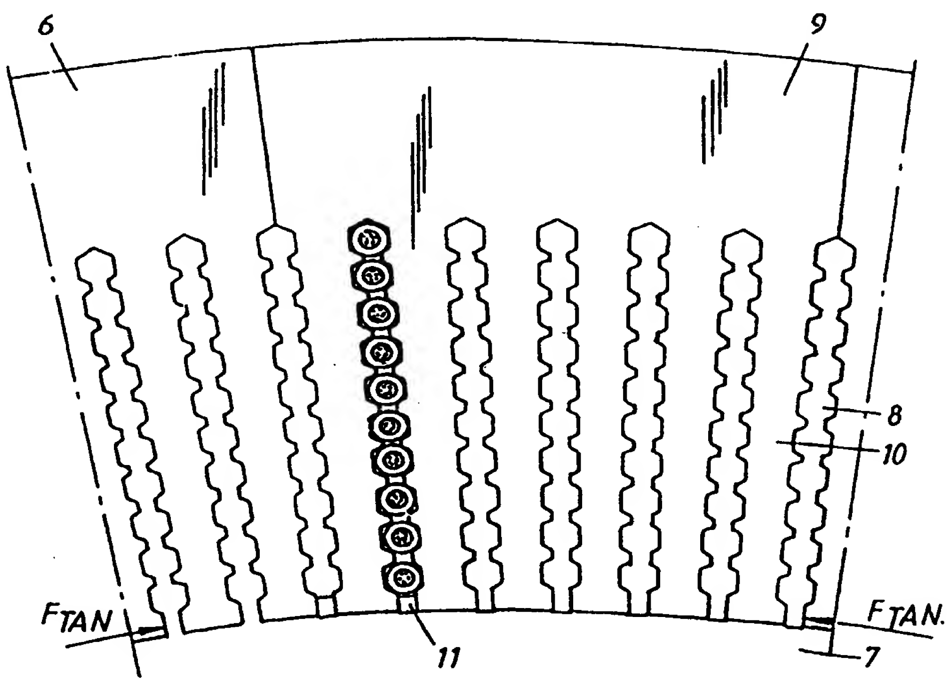

(57) Abstract

In a device for increasing the mechanical rigidity and natural frequency of th stator in a rotating lectric machine, which stator is provided with teeth (10) between the slots (8) receiving the winding, the free ends f said teeth being located in the air gap (7) between stator and rotor, a spacer (11) increasing rigidity is arranged in each space between the free ends of adjacent stat r teeth (10). These ends are thus fixed tangentially.

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A DEVICE IN THE STATOR OF A ROTATING ELECTRIC MACHINE

The present invention relates to a device for increasing the mechanical rigidity and natural frequency of the stator in a rotating electric machine and prevent damaging oscillations occurring between the stator teeth.

Certain attempts at a new approach as regards the design of synchronous machines are described, inter alia, in an article entitled "Water-and-oil-cooled Turbogenerator TVM-300" in J. Elektrotechnika, No. 1, 1970, pp 6-8, in US 4,429,244 "Stator of Generator" and in Russian patent document CCCP Patent 955369.

The water- and oil-cooled synchronous machine described in J. Elektrotechnika is intended for voltages up to 20 kV. The article describes a new insulating system consisting of oil/paper insulation, which makes it possible to immerse the stator completely in oil. The oil can then be used as a coolant while at the same time using it as insulation. To prevent oil in the stator from leaking out towards the rotor, a dielectric oil-separating ring is provided at the internal surface of the core. The stator winding is made from conductors with an oval hollow shape provided with oil and paper insulation. The coil sides with their insulation are secured to the slots made with rectangular cross section by means of wedges. As coolant, oil is used both in the hollow conductors and in holes in the stator walls. Such cooling systems, however, entail a large number of connections of both oil and electricity at the coil ends. The thick insulation also entails an increased radius of curvature of the conductors, which in turn results in an increased size of the winding overhang.

The above mentioned US patent relates to the stator part of a synchronous machine which comprises a laminated magnetic core of electrical steel with trapezoidal slots for the stator winding. The slots are tapered since the need of insulation of the stator winding is less towards the interior of the rotor where that part of the winding which is located nearest the neutral point is located. In addition, the stator part comprises a dielectric oil-separating cylinder nearest the inner surface of the core which may increase the magnetization requirement relative to a machine without this ring. The stator winding is made of oil-immersed cables with the same diameter for each winding layer. The layers are separated from each other

by means of spacers in the slots and secured by wedges. What is special regarding the winding is that it comprises two so-called half-windings connected in series. One of the two half-windings is located, centred, inside an insulation sleeve. The conductors of the stator winding are cooled by surrounding oil. The disadvantages with such a large quantity of oil in the system are the risk of leakage and the considerable amount of cleaning work which may result from a fault condition. Those parts of the insulation sleeve which are located outside the slots have a cylindrical part and a conical termination reinforced with current-carrying layers, the duty of which is to control the electric field strength in the region where the cable enters the end winding.

From CCCP 955369 it is clear, in another attempt to raise the rated voltage of the synchronous machine, that the oil-cooled stator winding comprises a conventional high-voltage cable with the same dimension for all the layers. The cable is placed in stator slots formed as circular, radially disposed openings corresponding to the cross-section area of the cable and the necessary space for fixing and for coolant. The different radially located layers of the winding are surrounded by and fixed in insulated tubes. Insulating spacers fix the tubes in the stator slot. Because of the oil cooling, an internal dielectric ring is also needed here for sealing the coolant against the internal air gap. The design shows no tapering of the insulation or of the stator slots. The design exhibits a very narrow radial waist between the different stator slots, which implies a large slot leakage flux which significantly influences the magnetization requirement of the machine.

The problem addressed by the invention appears in connection with a high-voltage electric alternating current machine, primarily intended as a generator in a power station for generating electric power. Such machines have conventionally been designed for voltages in the range 15-30 kV and 30 kV has normally been considered to be an upper limit. This generally means that a generator must be connected to the power network via a transformer which steps up the voltage to the level of the power network, i.e. in the range of 130-400 kV.

By using high-voltage insulated electric conductors, in the following termed cables, in the stator winding, with permanent insulation similar to

that used in cables for transmitting electric power, e.g., crosslinked polyethylene (XLPE) cables, the voltage of the machine can be increased to such levels that it can be connected directly to the power network without an intermediate transformer. The step-up transformer is thus eliminated.

This concept generally requires that the slots in which the cables are placed in the stator to be deeper than with conventional technology (thicker insulation due to higher voltage and more turns in the winding). This entails new problems with regard to mechanical natural frequencies in the stator teeth between the stator slots. A stator with deep slots may be subjected to damaging vibrations at the air gap due to resonance with disturbing force, typically electromagnetic forces with a frequency of 100 Hz for a machine having a nominal output frequency of 50 Hz.

The object of the present invention is to solve this problem and thus prevent oscillations between the stator teeth. This object is achieved with the method and the device defined in the appended claims.

The invention will now be described in more detail with reference to the accompanying drawings in which

Figure 1 shows a cross section through the insulated electrical conductor which is used in conjunction with the invention and is here termed a cable,

Figure 2 shows an axial view of a sector in a stator core,

Figures 3 and 4 show axial views of the end of a slot situated at the air gap in the stator core, according to two embodiments of the invention,

Figure 5 shows an axial view of a sector of a stator core according to a third embodiment of the invention,

Figure 6 shows an axial view of a sector of a stator core with yet another application of the device according to the invention,

Figure 7 shows an axial section through the stator part corresponding to Figure 6, and

Figures 8 and 9 show a radial and an axial view, respectively, partially in section, of the end part of the stator core near the air gap.

Figure 1 illustrates a cross-sectional view of an insulated electric conductor or cable 1, used in conjunction with the present invention. The cable 1 comprises a conductor 2 with circular cross section, consisting of a number of strands and made of copper, for instance. This conductor 2 is arranged in the middle of the cable 1. Around the conductor 2 is a first semiconducting layer 3. Around the first semiconducting layer 3 is an insulating layer 4, e.g., XLPE insulation. Around the layer of insulation 4 is a second semiconducting layer 5. In this context, therefore, the cable does not include the outer protective sleeve which normally surrounds a cable for power distribution.

Figure 2 shows part of a stator lamination 6 intended for a new high-voltage alternating current generator. These stator laminations 6, placed one on top of the other, form the core of the stator. This is annular and surrounds the rotor (not shown) with an air gap 7. Slots 8 to receive the cables extending axially through the stator are deeper than in conventional machines. This entails the above-mentioned drawbacks of the stator having low natural frequencies and that oscillations easily occur in the stator teeth 10.

In order to solve this problem it is proposed according to Figure 3 that a spacer or a slot wedge 11 is inserted into the opening of the slot 8. The wedge is made of a material which is electrically non-conducting and is non-magnetic, rigid and strong, e.g., glassfibre-reinforced plastic (epoxy plastic), and extends across the entire axial length of the stator. This wedge is inserted with radial force as indicated by the arrow 12 during assembly, thus providing tangentially stiff connections between the stator teeth at the air gap all round the stator. This stiff connection increases the natural frequency and offers greatly increased rigidity in each individual tooth, and even increased flexural rigidity in the whole stator core. Another important advantage is that the tangential electromagnetic forces at the air gap, deriving from the rotor poles, are distributed more uniformly between the teeth.

As can be seen in Figure 3, the wedge 11 does not abut the cables 1 with radial force, the nearest cable being shown in the drawing. As is clear from Figure 2, unlike in conventional generators, the slots 8 are designed in a shape similar to a bicycle chain, with recesses for each cable 1 which is thus radially fixed. In previously known generators the cable slots were of uniform width and the cables were pressed in with a radial force achieved by a slot wedge that gave no tangential loading. These previously known slot wedges thus had a completely different function from the slot wedge 11 according to the present invention, the only function of which is to achieve tangential pre-stressing F_{TAN}, which permits sufficiently rigid and strong connection between the free ends of the stator teeth.

Figure 4 shows another embodiment of the device according to the invention. Here the wedge 11 has inverted wedge shape, as also the wedge surfaces cooperating therewith on the stator teeth 10. Upon being placed under pressure the wedge is in this case pressed out towards the air gap, making use of the cable 1 radially fixed innermost in its seat. It is thus possible to utilize a tube, known per se which, upon being pressurized expands between the cable 1 and wedge 11, a tube 14 which is filled with, e.g., liquid epoxy compound which hardens under pressure. Such a tube has been used previously in conventional generators in order to press the conductors forming the winding into the slot outwardly towards the bottom of the slot, a function not at all demanded in the present case.

A third embodiment is shown in Figure 5. Here the tangential compression between the stator teeth is achieved via the wedges 11 by a tensile force F being applied to the stator core 15 through an external arrangement in the form of tie-rods, cords 16 or the outer stator frame 17. The stator consisting of segments is joined together at final assembly so that when tensile force is applied to the outer arrangement, a counter compressive force is obtained in the stator teeth and wedges at the air gap.

In Figures 3 and 4 the spacers 11 are wedge-shaped, as described. However, they may also be parallel-epipedic, in which case the tangentially stiff connection can be achieved in accordance with Figure 5.

Adhesive joints may also be arranged between the spacers 11 and stator teeth 10, either as the sole fixing means or prior to fixing by means of tangential clamping.

Figures 6-9 illustrate how the slot wedges according to the invention can also be utilized to achieve axial compressive pre-stressing of the stator core 15. The pressure fingers 18 are arranged on each side of the core 15, immediately opposite the stator teeth 10, to act as a force-transmission device to convert the tensile force in the wedges 11 to a uniformly distributed compressive force in the stator core 15. To achieve this the ends of the wedges are joined together by means of transverse pieces 19 which are able to cooperate with the pressure fingers 18. The transverse pieces 19 in the embodiment shown are joined to the wedges 11 by means of pins 20, slidable in the transverse pieces 19, which are loaded outwardly by means of a compression spring 21. One end of the pressure fingers 18 engages below the transverse piece 19, enabling it to load the transverse piece and thus the wedges in a direction outwards from the laminated core 15. The other end of the pressure fingers 18 is clamped between two devices 22 and 23 connected to the stator frame 17.

Instead of the transverse pieces 19, according to the right side of Figures 8 and 9 the tensile force in the wedge 11 can be converted to a compressive force in the stator core 15 via nuts 24 cooperating with screw threading 25 on the edges of the wedges 11. The compressive force from the nuts 24 is transmitted to the stator core 15 via plates 26 of, e.g., laminated glassfibre.

As shown in Figures 6-9 the slot wedges used for tangential positioning of the stator teeth are also utilized advantageously as tie-rods to achieve the requisite compressive stress in the stator core.

The invention is also applicable to other electric machines such as double-fed machines, applications in asynchronous static current converter cascades, outer pole machines and synchronous flux machines, particularly if their windings are manufactured with insulated electric conductors of the type described in the introduction, and preferably in the voltage range 36-800 kV.

CLAIMS

1. A device for increasing the mechanical rigidity and natural frequency of the stator in a rotating electric machine, which stator is provided with teeth (10) between the slots (8) receiving the winding, the free ends of said teeth being located in the air gap (7) between stator and rotor, **characterized** in that a spacer (11) to increase rigidity is arranged in each space between the free ends of adjacent stator teeth (10) to tangentially fix said ends.

2. A device as claimed in claim 1 **characterized** in that the spacer comprises a wedge (11).

3. A device as claimed in claim 2, **characterized** in that the wedge surfaces converge outwardly towards the ends of the stator teeth (10) connected to each other, the wedge (11) being arranged to be subjected to a radial, outwardly directed force during assembly.

4. A device as claimed in claim 2 **characterized** in that the wedge surfaces diverge outwardly towards the ends of the stator teeth (10) connected to each other, an expansion means (14) being arranged between the wedge (11) and the cable (1) of the winding situated nearest to the slot (8) and secured in a seat in the slot (8).

5. A device as claimed in claim 4 **characterized** in that the expansion means consists of a tube (14) which is filled with a liquid compound, such as epoxy plastic, which is curable under pressure.

6. A device as claimed in any of claims 1-5, **characterized** by adhesive joints between the spacers (11) and stator teeth (10).

7. A device as claimed in claim 1 or claim 2 **characterized** in that a clamping force is applied to the outer part of the stator core (15) by means of an outer stator frame (17) or an external arrangement in the form of tie-rods (16) thereby producing tangential compressive tangential forces on the surfaces of the spacers at the free ends of the stator teeth (10).

8. A device as claimed in any of claims 1-7 **characterized** in that the spacers (11), which extend the entire length of the stator, are designed as tie rods to axially pre-stress the stator core (15).

9. A device as claimed in claim 8 **characterized** in that a force-transmitting device (18) is arranged between the spacers (11) and the outer periphery of the stator and arranged to convert tensile axial stress in the spacers (11) to compressive axial stress in the stator core (15).

10. A device as claimed in claim 9, **characterized** in that the spacers (11) are connected together at their ends by means of transverse pieces (19) and in that the force-transmitting device consists of pressure fingers (18) extending radially on each side of the stator core (15) immediately opposite the stator teeth (10), the inner ends of said fingers protruding inside the transverse pieces (19) and the outer ends being pressed against the core (15) by means of a clamping device (22, 23) on the stator frame (17).

11. A device as claimed in claim 9 **characterized** in that the ends of the spacers (11) are provided with screw threading (25) for cooperation with a nut (24) to transfer compressive force via a plate (26) to the stator teeth (10).

12. A rotating electric machine **characterized** by a device as claimed in any of claims 1-11 to increase the natural frequency of the stator.

13. A rotating electric machine according to claim 12 **characterized** in that the winding comprises at least one current-carrying conductor (2), a first layer (3) having semiconducting properties provided around said conductor (2), a solid insulating layer (4) provided around said first layer (3), and a second layer (5) having semiconducting properties provided around said insulating layer (4).

14. A rotating electric machine according to claim 13, **characterized** in that the potential of said first layer (3) is substantially equal to the potential of the conductor (2).

15. A rotating electric machine according to claim 13 or 14, **characterized** in that said second layer (5) is arranged to constitute substantially an equipotential surface surrounding said conductor (2).

16. A rotating electric machine according to claim 15, **characterized** in that said second layer (5) is connected to a predetermined potential.

17. A rotating electric machine according to claim 16, **characterized** in that said predetermined potential is earth potential.

18. A rotating electric machine according to any one of claims 13 - 17, **characterized** in that at least two adjacent layers have substantially equal thermal expansion coefficients.

19. A rotating electric machine according to any one of claims 13 - 18, **characterized** in that said current-carrying conductor (2) comprises a number of strands, only a minority of said strands being non-isolated from each other.

20. A rotating electric machine according to any one of claims 13 - 19, **characterized** in that each of said three layers is fixed connected to adjacent layer along substantially the whole connecting surface.

21. A rotating electric machine according to any one of claims 13 - 20, **characterized** in that said cable (1) also comprises a metal shield and a sheath.

Fig. 1

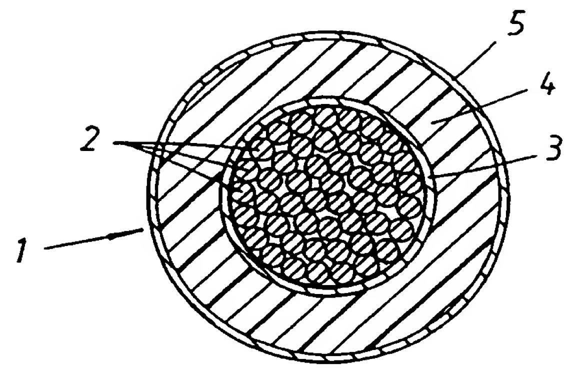

Fig. 2

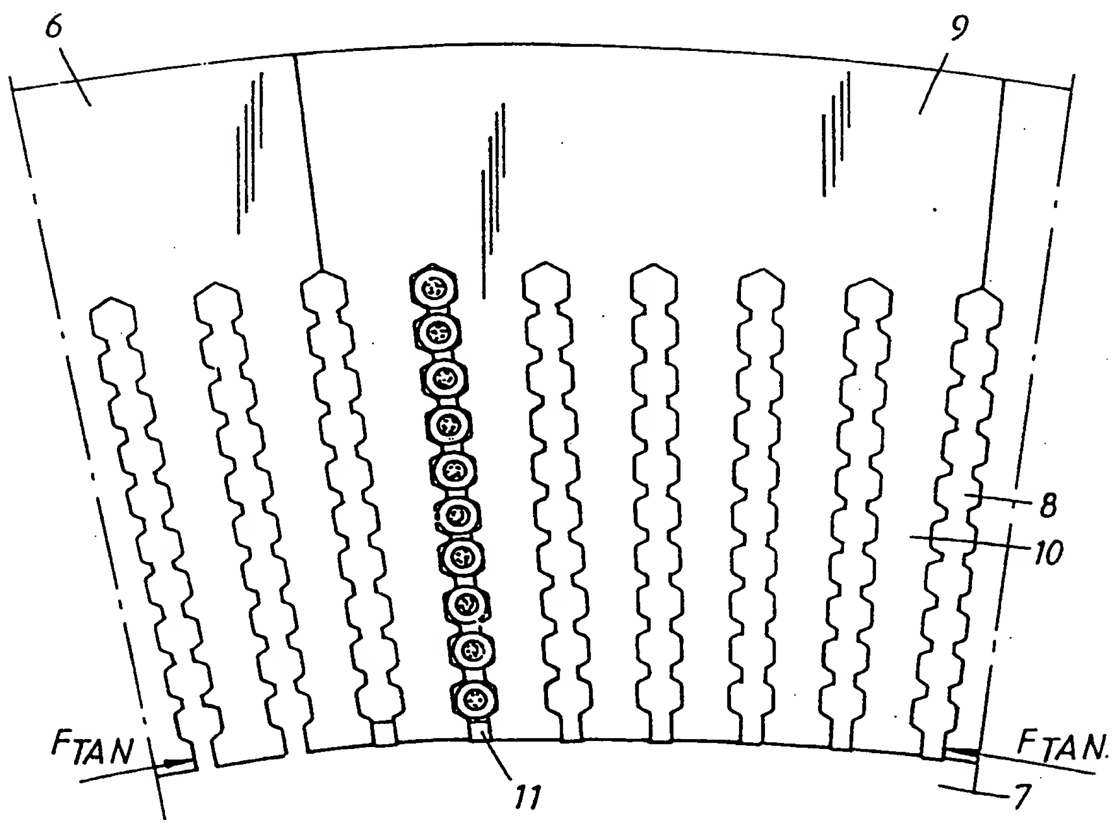

Fig. 3

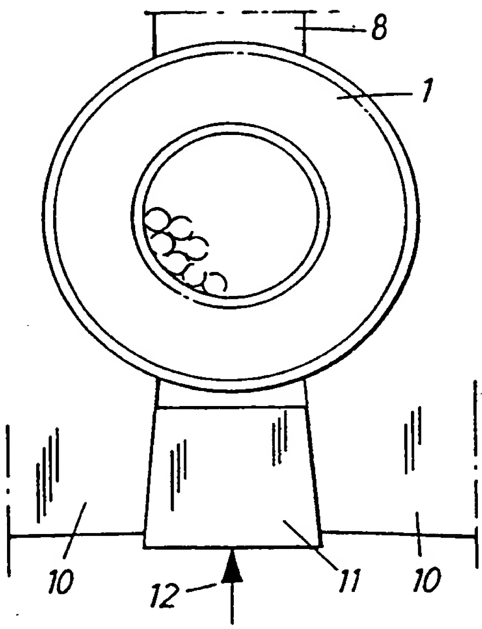

Fig. 4

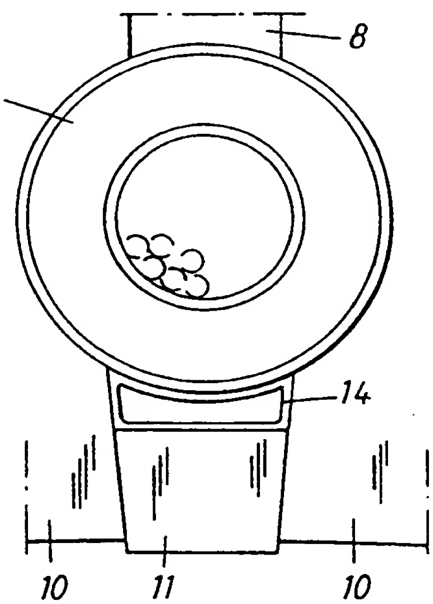

Fig. 5

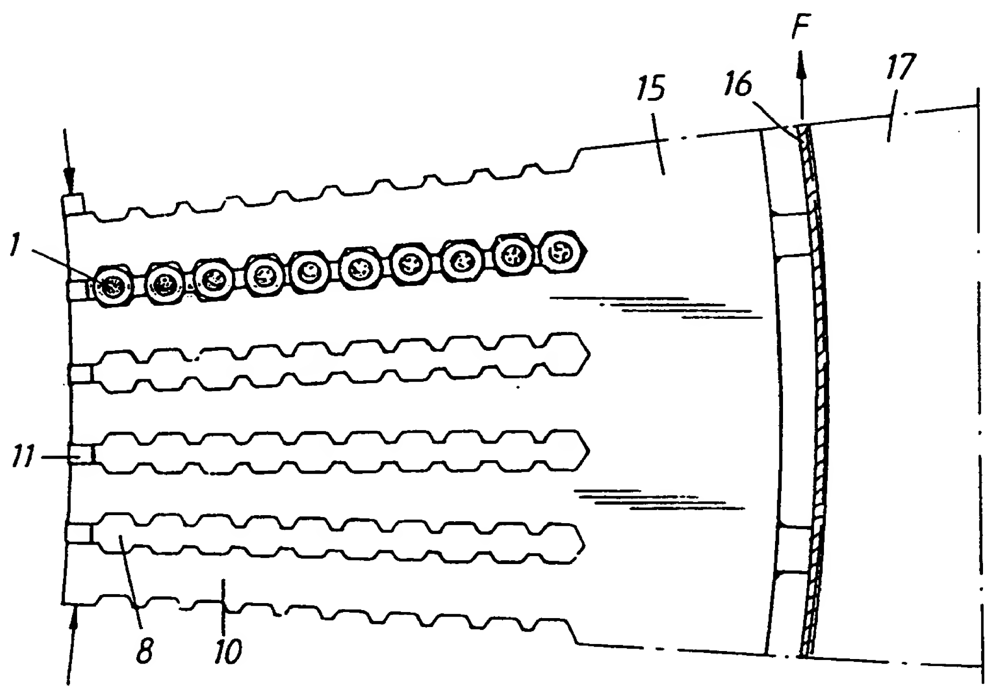

Fig. 6

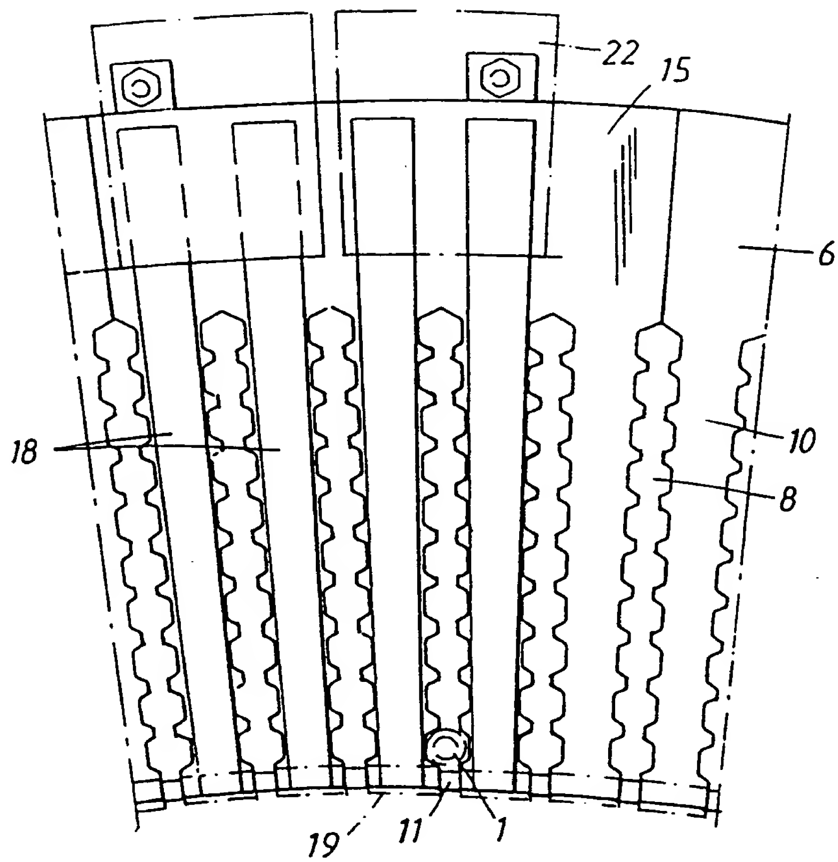

Fig. 7

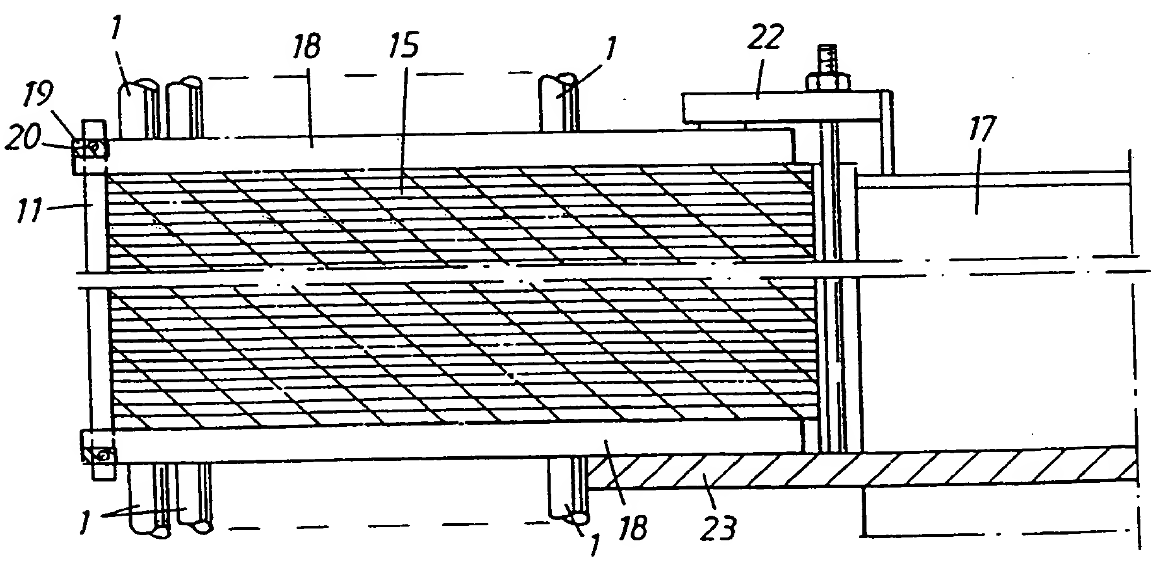

Fig. 8

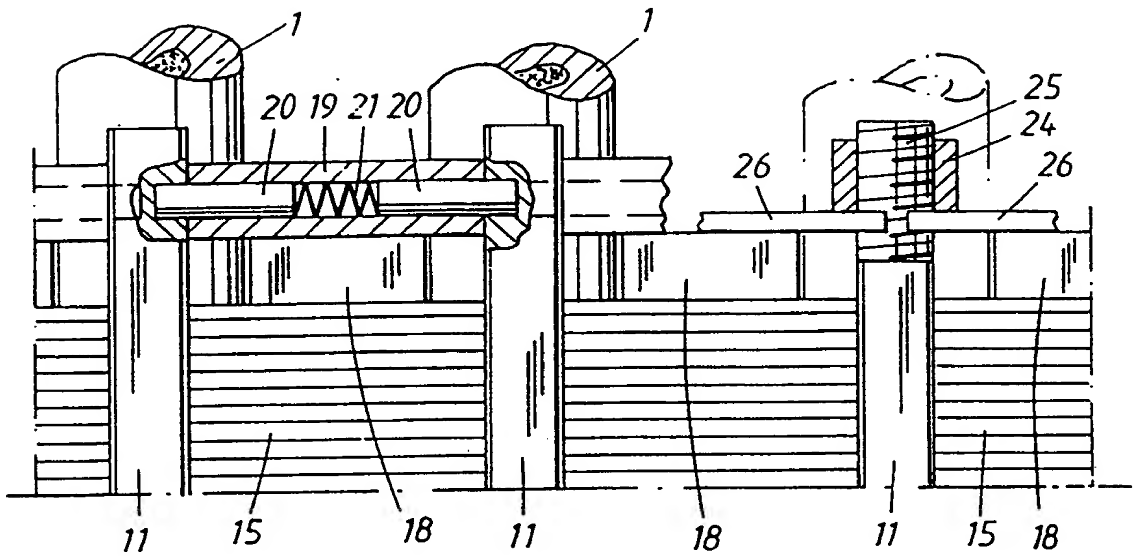
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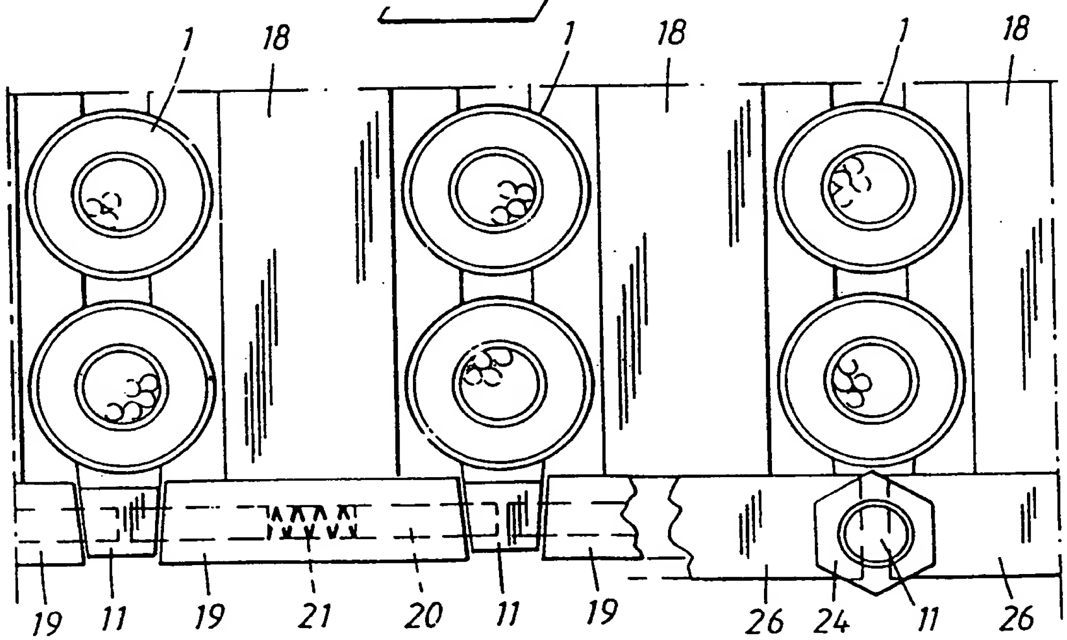
Fig. 9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INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE 97/00904

A. CLASSIFICATION OF SUBJECT MATTER

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B. FIELDS SEARCHED

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Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

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Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

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C. DOCUMENTS CONSIDERED TO BE RELEVANT

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A		3,7-11
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X	US 3437858 A (R.B. WHITE), 8 April 1969 (08.04.69), column 1, line 1 - line 20	1-2
Y		5-6
A		3-4,7-11
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[X] Further documents are listed in the continuation of Box C. [X] See patent family annex.

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C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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Information on patent family members

01/09/97

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